Discussion of the Effect of Reshimming on the Coupling in the Tevatron

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Introduction

In the collider run during the early part of 2003 it was realized that there was considerably more coupling in the Tevatron then was thought to have been the case in the early days of Tevatron operation. Almost simultaneously it was discovered, on the basis of measurements made on the dipoles in the tunnel, that the "cold lift" of Tevatron dipoles had changed, and that the measured change could account for the observed coupling. As a result of the observations, and because of the desire to reduce the coupling, the cold lift of approximately 112 magnets was corrected in the fall of 2003. The results were encouraging; the currents in the skew correction circuits were reduced from their previous values. Analysis indicated that the current in the **sqa0** circuit could be reduced further if the cold lift were corrected in an additional 12 magnets. That correction was made in March 2004.

The expectation that the changes made in March 2004 would have a small and generally positive effect, i.e. reduction in magnitude, in the skew quadrupole currents turned out to be wrong. The current in the **sqa0** increased significantly from the current in the circuit before the March shutdown. The data are contained in Table I.

Table I

Current in Skew Quadrupole and Chromaticity Sextupole Circuits

(from T39 files)

Lattice	Injection	Injection	Injection	Collision	Collision	Collision
T39 file	98	293	996	100	464	42
Energy (GeV)	150	150	150	980	980	980
Date	8/15/2003	11/26/2003	4/15/2004	8/15/2003	12/3/2004	5/13/2004
Circuit	*Current (A)*	*Current (A)*	*Current (A)*	*Current (A)*	*Current (A)*	*Current (A)*
T:SQ	-2.952	-3.027	-2.727	-28.08	-25.43	-26.48
T:SQA0	4.248	2.973	4.248	34.77	2.698	19.25
T:SQA4	-5.145	0.0109	0.0172	-33.77	0.0109	4.511
T:SQB1	0.5656	0.0031	0.0047	3.922	0.0047	4.509
T:SQD0	0.0234	0.0234	0.0234	0.7484	0.0234	0.0234
T:SQE0	1.498	1.498	-0.1016	0.0234	-0.0016	-0.0766
T:SF	2.648	2.273	2.523	5.923	10.52	10.55
T:SD	-0.0516	-0.8266	0.0234	-23.03	-29.18	-29.2

This note is an attempt to understand why this might be so and where the analysis done before the shutdown might have been in error.

Model and Analysis

I am using a Tevatron model based on the MAD files distributed on the web. The calculations are done using Tevlat[1]. The high multipoles used in the calculations were derived from measurements done at MTF. The calculations were done with the injection lattice at an energy of 150GeV and with the collision lattice at an energy of 980GeV.

The moments used in the analysis come from the MTF data stored in the magnet information database [2]. The MTF measurements have been modified to reflect the cold lift problems, the reshimming done in the Fall of 2003 and the additional reshimming done in March 2004. Three conditions were considered:

1. The values of the a_1 multipole for the dipoles was increased by +1.4units (identified as *a1p14*);
2. The values of the a_1 multipole for the dipoles from a44-1 to b19-5 and from c44-1 to d19-5 were restored to their original MTF values. This corresponds to the reshimming done in the fall of 2003 (identified as *a1p14.fix1*);
3. In addition to the dipoles from a44-1 to b19-5 and from c44-1 to d19-5 the dipoles from b48-1 to b48-5, d48-1 to d48-5, e48-1 to e48-5, and from f48-1 to f48-5 were restored to their original MTF values2003 (identified as *a1p14.fix1.fixs*).

There are therefore six cases to consider[3]:

	Injection at 150 GeV		Collision at 980Gev
Case	Moment file	Case	Moment file
1	*y011009.a1p14*	4	*x011009.a1p14*
2	*y011009.a1p14.fix1*	5	*x011009.a1p14.fix1*
3	*y011009.a1p14.fix1.fixs*	6	*x011009.a1p14.fix1.fixs*

For each of the six cases the following procedure was used:

1. The tunes were brought to the values of $\nu_x = \nu_y = 0.581921$ by adjusting the values of the T: QF, T:QD, T:SQ, T:SQA0, and T:SQB1. The currents in the other skew quadrupoles were left at zero.

2. The settings of the skew quadrupole circuits were then fixed and the T:QF, T:QD, T:SF and T:SD circuits were adjusted to set the tunes and chromaticities to:

	x	y
Tune	0.58680	0.57703
Chromaticity	8.4	8.2

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[1] A. Russell, private communication.

[2] These data are now available in the "BLASTMAN" database on the web.

[3] The moments for the injection lattice were those measured by the staff at MTF at 660A while the moments for the collision lattice were measured at 4000A. The sextupole moments b_2 are very different at the two currents.

3. In addition a loose constraint was imposed on the value of the β functions at C0. I tried to maintain them at their uncoupled value of 75*m*.

The results from fitting the currents are shown in Table II.

Table II
Calculated Values of the Correction Currents.

Lattice	Injection	Injection	Injection	Collision	Collision	Collision
Case	1	2	3	4	5	6
Circuit	*Current*	*Current*	*Current*	*Current*	*Current*	*Current*
T:SQ	2.72	2.41	2.41	18.21	17.51	17.35
T:SQA0	-3.60	-2.22	-2.60	12.07	-0.28	-2.39
T:SQB1	2.74	1.11	0.92	1.57	-2.22	-2.43
T:SF	3.85	3.87	3.86	14.15	14.21	14.2
T:SD	0.68	0.67	0.66	-30.37	-30.36	-30.35

Discussion

The calculated values do not agree with the measured values of the currents. We should not expect perfect agreement since the model used is surely not complete nor are the inputs, i.e. the high order multipoles, completely accurate. Nonetheless the general features of the calculations agree, except in one case with the actual currents in the Tevatron.

The difference in the sign of the skew quadrupole currents is due to a different definition of the sign of the coupling. I will ignore the sign of the currents in the skew quadrupoles and focus on its magnitude.

At injection the current in the T:SQA0 decreased by 1.3A after the first reshimming. This agrees remarkably well with the calculated decrease of 1.4A. The calculations suggest only a small change in the T:SQ current and that is what is seen.

At injection, after the last reshimming, the measured value of the current in the T:SQA0 has reverted to its value before the first reshimming. The calculated value shows the expected small change (though the current increased rather than decreased). Additional calculations, beyond what are being discussed here; show that the solutions are far from being unique. The parameters used in the fitting can be strongly correlated. Thus a solution can exist with a small value of the T:SQA0 current or with a much larger value, with small, or sometimes large, changes in the other fitting parameters.

With the collision optics we see a similar situation. For both the actual currents and the calculated currents we see the current in T:SQA0 decrease to a very small value with only a small change in T:SQ after the first reshimming. In the machine however after the second reshimming the current in T:SQA0 shows an increase with a change in T:SQ. A calculated solution can, however, be found with a small T:SQA0 and only a small change in T:SQ.

Thus we are faced with a conundrum. Our model, though crude, is good enough to predict, reasonably well[4] in my opinion, the currents in the skew quadrupole correction circuits for the original configuration and after the first reshimming both for the injection and collision lattices. The model fails badly in predicting the results of the second reshimming. We expected small changes whereas there were large changes in the currents used in the Tevatron.

I can think of, at least, two possibilities. We could be operating at an alternative solution, one different from the one described in Table II. In which case we should look for a solution with a smaller value of T: SQA0, closer to that in Table II. The other possibility is that there is a new source of coupling not yet described in the model. Perhaps looking at the crossed plane amplitude when a dipole kick is applied to the beam can provide an answer. I will try that analysis with data taken by V. Lebedev.

Addition Results From Tracking.

With the calculated values of the corrector currents and the lattice description we can calculate the predicted properties of the Tevatron under the different conditions. The results are shown in table III. These calculations should not be taken as definitive but rather as suggestive. I would conclude that the reshiming to correct the cold lift, and the calculated retuning should provide some small improvements in the performance of the Tevatron. The incomplete model used also predicts a larger luminosity at B0 that at D0.

Table III
Calculated Lattice Properties.

Case	1	2	3	4	5	6
DA/π(ε_x=ε_y)(*mmmr*)[5]	290	300	310	270	270	300
Smear	0.139	0.129	0.112	0.097	0.208	0.202
β_x(B0)	1.7153	1.6489	1.6467	0.3084	0.3161	0.3157
β_y(B0)	1.7742	1.743	1.7258	0.3154	0.3161	0.3160
β_x(D0)	1.6555	1.5926	1.5962	0.3412	0.3354	0.3354
β_y(D0)	1.9983	1.9264	1.9186	0.4718	0.4836	0.4838
$(\beta_x(B0)*\beta y(B0))^{1/2}$				0.3119	0.3161	0.3158
$(\beta_x(D0)*\beta y(D0))^{1/2}$				0.4012	0.4027	0.4028
Lum. Ratio(B0/D0)				1.2865	1.2741	1.2754

[4] Not well enough to set the currents in the Tevatron but well enough to anticipate the behavior of the Tevatron as the model is changed.
[5] The dynamic aperture is calculated using a physical aperture of 35*mm*.